Teármann Research Ecosystem · Internal Technical Report
Genesis Artificial Life Laboratory

Dihypersphaerome ventilans

3Hy2v · 乙超球 · Second Hypersphere

A four-dimensional Lenia species: characterization from first principles, analytical hyperrotation rendering, and integration as a seeding layer for a multi-channel two-dimensional ecosystem.

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Abstract. *Dihypersphaerome ventilans (code 3Hy2v, 乙超球, second hypersphere) is a spatially localized pattern discovered by Bert Wang-Chak Chan in four-dimensional Lenia (Chan, 2020). It exhibits stationary oscillation — so-class behavior designated ventilans (Latin, to fan, to breathe) — pulsing rhythmically in place without translation or rotation. Its defining feature is a three-shell kernel with* $\boldsymbol{\beta} = (\frac{1}{12}, \frac{1}{6}, 1)$*: the outer ring is twelvefold stronger than the inner, making the organism's boundary more important to its physics than its interior. We characterize the species from first principles, derive the ecological significance of its narrow survival band* ($\sigma = 0.033$)*, describe an analytical 4D hyperrotation simulation approach implemented in WebGL2 shaders, and document its integration as a seeding layer for a multi-channel 2D ecosystem. The organism seeds the world it moves through without being visible in it.*

Keywords: Lenia · 4D cellular automata · artificial life · hyperrotation · predator–prey ecology · morphogenetic fields · flow advection

§1 Discovery and Context

Specimen Record · Lenia Expanded Universe · Class 4D

Species	*Dihypersphaerome ventilans*
Code	3Hy2v
Chinese	乙超球 (*Yĭ Chāo Qiú*) — *second hypersphere*
Domain	Simulata → Lenia → 4D
Behavior class	so — stationary oscillation
Subcategory	*ventilans* (ventilating / breathing)
Source	Chan (2020), `animals4D.json`
Discovery	Semi-automatic search, 4D parameter space
Dimensional	4D toroidal grid (N^4)
Rarity	Named species — extremely rare

Chan's 2020 alife paper *Lenia and Expanded Universe* extended the original two-dimensional Lenia framework to higher dimensions, multiple kernels, and multiple coupled channels — discovering phenomena including polyhedral symmetries, individuality, self-replication, emission, growth by ingestion, and *virtual eukaryotes* with internal division of labor. Among the 4D organisms discovered through semi-automatic search, *D. ventilans* stands apart: it does not move, does not grow, does not divide. It *breathes*.

The species code 3Hy2v encodes its architecture precisely: three peak kernel shells; Hy (*hyper*, higher-dimensional); the 2 denoting second genus in the family; `v` for *ventilans*. The Chinese name 乙超球 translates as *second-class hypersphere*, where 乙 is the second Heavenly Stem (used in ordering like A, B, C) and 超球 is *hypersphere*. It is, formally, the *second* hyperspherical organism in Chan's taxonomy.

Its extreme rarity follows from its dimensional requirements. Standard 2D Lenia observers never encounter it — its 2D cross-sections are near-empty at the poles of its 4D body. The organism reveals itself only when observed from the *equatorial* hyperplane, and even then only as a faint ring structure. Most searches that would find an *Orbium*, a *Scutium*, or an *Ignis* in 2D pass through *D. ventilans*'s parameter neighborhood without registering its existence.

The observational geometry problem

D. ventilans cannot be observed directly in 2D. A 4D organism projects into the 2D observation plane as a cross-sectional slice whose shape depends entirely on the orientation of the cutting hyperplane. At the poles of the 4D body the cross-section reduces to a point or vanishes; at the equatorial plane it reveals the full ring structure. Most 2D observers — and most automated parameter searches — pass through *D. ventilans*'s niche without registering its existence.

The *echolocation ring* overlay in Genesis renders this problem visible: three concentric circles at radii $R/3$, $2R/3$, and R (weighted by $\beta_1, \beta_2, \beta_3$ respectively) show the organism's kernel geometry as a spatial overlay. What you are seeing is the *sensory field* — the geometry by which *D. ventilans* perceives its own neighborhood at each moment of its ventilating cycle.

§2 Parameters and the Shell Kernel

Param	Value	Role	Ecological interpretation
R	10	Radius	Neighborhood radius. Medium range — neither the slow giants at $R = 20$ nor the twitchy sprinters at $R = 5$.
T	10	Time	$dt = 1/T = 0.1$. Moderate temporal sampling; the breath cycle is visible at real time.
β_1	$1/12$	Inner ring	Weight 0.083. Barely a whisper — this ring is almost acoustically silent.
β_2	$1/6$	Middle ring	Weight 0.167. Dim — secondary structural sensing.
$\boldsymbol{\beta_3}$	**1**	**Outer ring**	**Dominant.** $12\times$ inner, $6\times$ middle. *The organism* is *its surface.*
μ	0.18	Growth centre	Each cell "wants" average activation 0.18 in its outer-ring neighborhood to be in homeostasis.
σ	0.033	Tolerance	Very narrow: $G = 0$ at $u = 0.147$ and $u = 0.213$. Window $= 0.066$ units. Among the tightest in the taxonomy.

Table 1: Canonical parameters for *D. ventilans* from Chan (2020), `animals4D.json`, code 3Hy2v. The highlighted row $\beta_3 = 1$ is the defining constraint of the species.

2.1 The shell kernel formula

The kernel value at normalized radius $r \in [0, 1)$ from the organism's centre is a three-shell partition of Chan's standard exponential bump:

$$K(r) \;=\; \beta_k \cdot \exp\!\Big(4 - \frac{4}{4\,t\,(1-t)}\Big), \qquad \begin{cases} k = \lfloor rn \rfloor & \text{(ring index)} \\ t = rn - k & \text{(local position in ring)} \\ n = 3 & \text{(number of shells)} \end{cases} \tag{1}$$

with $\boldsymbol{\beta} = (\frac{1}{12}, \frac{1}{6}, 1)$ and outer-ring dominance $\beta_3/\beta_1 = 12$. The core function $\exp\!\big(4 - 4/(4r(1-r))\big)$ is zero at $r = 0$ and $r = 1$ (ring boundaries), peaks at $r = 0.5$ within each partition, and is infinitely smooth everywhere. After normalization (dividing by the sum of all kernel weights over the grid), the outer ring's *dominance* is preserved but the kernel itself integrates to unity over the full neighborhood, so the potential field U remains in $[0, 1]$ regardless of the β distribution.

2.2 Acoustic silence of the interior

A cell at the centre of the organism ($r = 0$ relative to its neighbors' positions) contributes almost nothing to those neighbors' potential computations — because the kernel value at $r \approx 0$ (inner ring, weight $1/12$) is tiny. Conversely, a cell at the organism's surface ($r \approx 5R/6 \approx 8.3$ cells from any given internal cell) contributes enormously, with kernel weight near 1.0.

This is the defining biology of *D. ventilans*: **the skin does all the sensing.** The interior is nearly acoustically isolated from its own neighborhood potential. A useful analogy: imagine a starfish whose neural network lives entirely in its arm tips and whose body core can barely feel itself. *D. ventilans* experiences its own existence at its boundary, not its centre. The hyperspherical shell geometry enforces this — in 4D, surface area scales as r^3 while volume scales as r^4, making the surface an even larger fraction of the total structure than it is in 3D.

2.3 The narrow survival band

The growth function for Lenia is the standard Gaussian-difference form

$$G(u) \;=\; 2\,\exp\!\Big(-\frac{(u-\mu)^2}{2\sigma^2}\Big) - 1. \tag{2}$$

For *D. ventilans*, $\mu = 0.18$, $\sigma = 0.033$, yielding zero-crossings

$$u_{\text{low, high}} \;=\; \mu \pm \sigma\sqrt{2\ln 2} \;=\; 0.147,\; 0.213, \tag{3}$$

i.e. a survival window of 0.066 units in potential space. This is narrow but not extreme among named species: *Orbium* at $\sigma = 0.017$ has a window of ~ 0.023; *Ignis* at $\sigma = 0.012$, a window of ~ 0.016 (among the tightest on record).

What distinguishes *D. ventilans*'s situation is that this narrow band must be maintained simultaneously across *all 2D cross-sections of a 4D body.* In a 4D grid, a hyperspherical pattern generates potential gradients in four independent directions at once. The pattern can only sustain itself if its 4D geometry keeps every cell's potential within $[0.147, 0.213]$ at all times despite the four-dimensional interference of its own shell rings. This is the constraint that makes *D. ventilans* a 4D organism rather than a 2D one.

§3 Four-Dimensional Biology

A 4D Lenia organism exists on a toroidal grid of four spatial dimensions. Its body is a *soliton* — a self-sustaining spatially localized pattern — in four-dimensional continuous space. Observation requires choosing a cutting hyperplane: a 2D subspace of the 4D space. The cross-section depends entirely on which hyperplane is chosen and at what orientation.

3.1 Hyperspherical shell structure

D. ventilans's 4D body is nested 3-spheres (S^3): the same relationship that holds between a circle (S^1) and a disk in 2D, or a sphere (S^2) and a ball in 3D. The three β rings correspond to three nested S^3 surfaces:

Shell	4D Radius	β Weight	2D Cross-section	Role
Outer S^3	$\sim 5R/6$	1.000	Bright ring at equator	Dominant sensing surface
Middle S^3	$\sim R/2$	0.167	Faint inner ring	Secondary structure
Inner S^3	$\sim R/6$	0.083	Barely visible disk	Ghost of a core

Table 2: 4D shell structure of *D. ventilans*. The outer S^3 row is highlighted because $\beta_3 = 1.0$ makes it the dominant feature — twelvefold brighter than the inner shell.

3.2 The ventilating oscillation — mechanism

The *ventilans* behavior is a limit cycle in the 4D state space. The mechanism: the hyperspherical body expands slightly, pushing cells at its outer S^3 shell into regions of lower potential (the neighborhood density thins as the shell enlarges). When U drops below $\mu - \sigma$ at those cells, G turns negative; the shell contracts. Overshoot is guaranteed by the finite time step $dt = 0.1$. The system oscillates around the fixed point where every cell's potential exactly equals $\mu = 0.18$.

The period of oscillation depends on the local slope of G at μ — which is 0 at the centre (G is maximally flat at its peak) — and on dt. For *D. ventilans*'s parameters the breath cycle completes approximately every 30–40 simulation steps at spf $= 1$, $dt = 0.1$, corresponding to real time on the order of seconds in the Genesis display running at 60 fps.

3.3 Dimensional comparison

Property	*D. ventilans* (4D)	*Hexalapillium* (2D)	Typical *Orbium* (2D)
Dimension	4D toroidal	2D toroidal	2D toroidal
Behavior	so: *ventilans*	so: *ventilans*	to: translating
Symmetry	$O(4)$ hyper	Radial	Bilateral
Kernel peaks	3 (β-vector)	1 (single)	1 (single)
β_3	1.0 (dominant)	1.0	1.0
σ	0.033	$\sim$0.020	0.017
R	10	$\sim$8	13
Cross-section	Ring → point	Disk	Disk
Rarity	Extremely rare	Rare	Common

Table 3: Comparison of *D. ventilans* with related so species. Shaded column: key distinction — $O(4)$ symmetry makes *D. ventilans* orientation-free. No preferred axis in 4D.

§4 Simulation Architecture

A true 4D Lenia simulation on a 256^4 grid would require 4,294,967,296 cells — computationally intractable in real-time WebGL2. Genesis uses an *analytical 4D hyperrotation* approach: *D. ventilans*'s density is approximated analytically from its known shell geometry, and its temporal evolution is modeled as rigid 4D rotation. This correctly produces the ventilating oscillation in 2D projection.

4.1 HYPER_FRAG shader pipeline

```
// Step 1: Map UV pixel to centered 4D position
vec2 xy = (v_uv - 0.5) * 2.2;           // scale to [-1.1, 1.1]
vec4 p4 = vec4(xy.x, xy.y, 0.0, u_wSlice);

// Step 2: Apply 4D rotations (3 independent planes)
p4 = rotXW(p4, u_rotXW);                // lateral tumble X
p4 = rotYW(p4, u_rotYW);                // lateral tumble Y
p4 = rotZW(p4, u_rotZW);                // THE BREATH - ZW rotation

// Step 3: Sample analytical DV density at rotated 4D position
float r     = length(p4) / u_R4D;
float outer = exp(-pow((r - 0.85) / 0.08, 2.0)) * 1.000;
float mid   = exp(-pow((r - 0.55) / 0.10, 2.0)) * 0.167;
float inner = exp(-pow((r - 0.20) / 0.12, 2.0)) * 0.083;
float density = clamp(outer + mid + inner, 0.0, 1.0);

outColor = vec4(density, density, density, 1.0);  // ch3 texture
```

Listing 1: hyper_frag — WebGL2 fragment shader, runs per pixel per frame.

The zw rotation *is* the breathing. As `u_rotZW` accumulates, the 4D body's W-axis sweeps through the observation plane and the cross-section ring pulses in and out exactly as the true 4D so dynamics would produce. The xw and yw rotations are smaller and add the lateral tumbling characteristic of full 4D dynamics. Setting all rotation rates to zero freezes *D. ventilans* at a static cross-section, showing only its equatorial ring structure.

4.2 The 4D rotation matrices

```
// Rotation in XW plane (x-axis tilts into W dimension)
vec4 rotXW(vec4 p, float a) {
  return vec4(cos(a)*p.x - sin(a)*p.w,
              p.y, p.z,
              sin(a)*p.x + cos(a)*p.w);
}

// Rotation in ZW plane - primary breathing rotation
vec4 rotZW(vec4 p, float a) {
  return vec4(p.x, p.y,
              cos(a)*p.z - sin(a)*p.w,
              sin(a)*p.z + cos(a)*p.w);
}

// Accumulated angle each frame: theta += speed * 0.016
// Default ZW speed = 0.18 rad/s  =>  ~35s per full rotation
```

Listing 2: 4D rotation matrices in glsl. The zw plane carries the breath; xw/yw add asymmetric tumble.

4.3 Interface controls

Control	Range	Default	Effect
zw rotation	0–0.8	0.18 rad/s	Breathing rate. $0.18 \approx 1$ breath / 35 sim-sec
xw rotation	0–0.4	0.05 rad/s	Lateral X tumble — asymmetric cross-sections
yw rotation	0–0.4	0.07 rad/s	Lateral Y tumble — breaks circular symmetry
W slice	-1.0–1.0	0.0	Resting hyperplane. $0 =$ equatorial (max visibility)
4D amplitude	0–1.5	0.65	Density of projected 4D shadow in ch3
4D bleed	0–0.5	0.12	Coupling from ch3 into prey ch0 — seeding strength

Table 4: 4D simulation interface controls in Genesis. The 4D bleed parameter is the causal bridge from the 4D body to the 2D ecosystem.

§5 Multi-Channel Ecosystem Integration

The Genesis Lenia Expanded Universe substrate runs four coupled channels simultaneously on a shared 256×256 RGBA float texture (one `RGBA32F` pixel per simulation cell):

5.1 Cross-channel coupling equations

```
// Channel 0: Prey
U0 = K0 * A0                               // convolve prey kernel
```

Channel	Color	Species	Kernel & parameters
R (ch0)	Gold / amber	Prey (*Orbium*-class)	$R{=}13$, $\beta{=}(1)$, $\mu{=}0.15$, $\sigma{=}0.017$
G (ch1)	Electric cyan	Predator (*Ignis*-like)	$R{=}15$, $\beta{=}(\frac{1}{3},\frac{2}{3},1)$, $\mu{=}0.26$, $\sigma{=}0.036$
B (ch2)	Deep teal	Morphogen (diffuse)	$R{=}20$, $\beta{=}(1,0.5,0.1)$, $\mu{=}0.15$, $\sigma{=}0.028$
A (ch3)	Violet / white	*D. ventilans* (4D)	Analytical hyperrotation, $R_{\mathrm{4D}}{=}0.85$, $\omega_{\mathrm{zw}}{=}0.18$

Table 5: Four-channel state layout. *D. ventilans* is the only channel computed analytically rather than via convolution.

```
G0 = grow(U0, mu0, sigma0_eff)              // growth at effective sigma
G0 -= c01 * A1                              // predator suppresses prey
G0 += A3 * hyperMix * 0.4                   // 4D shadow seeds nucleation

// Channel 1: Predator
U1 = K1 * A1                                // convolve predator kernel
G1 = grow(U1, mu1, sigma1_eff)
G1 += c10 * A0 - 0.012                      // prey feeds predator; starvation

// Channel 2: Morphogen
U2 = K2 * A2                                // wide diffuse convolution
sigma0_eff = sigma0 * (1 + c20 * (A2 - 0.3))// morphogen widens prey niche

// Advection (applied before convolution, all channels)
phi = FLOW_FRAG(A0, A2)                     // velocity from gradients
A   = advect(A, grad(A) dot phi)            // Eulerian backward advection
```

Listing 3: sim_frag — the full update rule, per simulation step. `hyperMix` is the causal dial from 4D shadow to 2D ecology.

The `hyperMix` parameter is the causal bridge between the 4D and 2D worlds. At `hyperMix` = 0, ch3 (*D. ventilans*) is cosmetic — a violet overlay with no coupling. As `hyperMix` increases, the 4D shadow actively nudges prey activation wherever the rotating *D. ventilans* body intersects the 2D plane. Since this intersection pulses spatially and temporally as zw rotation proceeds, the prey nucleation sites move around the field in synchrony with *D. ventilans*'s breath.

5.2 The DV Seed preset — emergence from hyperspace

The most striking demonstration is the dv seed initial condition: all 2D channels begin empty. Only ch3 is initialized with the analytical *D. ventilans* ring structure at the grid centre.

```
for each pixel (x, y) in [0, N)^2:
  nx = (x / N - 0.5) * 2.2                  // centered, normalized
  ny = (y / N - 0.5) * 2.2
  r  = sqrt(nx^2 + ny^2)

  // Three DV rings at their beta-weighted radii
  ring3 = exp(-((r - 0.85) / 0.08)^2) * 1.000
  ring2 = exp(-((r - 0.55) / 0.10)^2) * 0.167
  ring1 = exp(-((r - 0.20) / 0.12)^2) * 0.083

  data[(y*N + x)*4 + 3] = ring3 + ring2 + ring1   // ch3 only
  // ch0 = ch1 = ch2 = 0.0 (empty ecosystem)
```

Listing 4: dv seed initial condition (`buildEcosystem('hyperseed')`). Only ch3 (alpha) receives nonzero values; the rest of the ecosystem bootstraps from the β_3 ring.

From this — a single glowing ring of 4D origin, no prey, no predator, no morphogen — the ecosystem bootstraps itself. As zw rotation proceeds, the outer ring ($\beta_3 = 1$, the dominant shell) appears and disappears as it sweeps through the 2D observation plane. Wherever it appears, prey nucleates from the `hyperMix` coupling. Predators do not appear spontaneously in this preset — they require separate seeding or painting. But the prey field that emerges is shaped, from its first moment of existence, by the geometry of a creature that lives four dimensions away.

Causal transparency · claire alignment argument

Every causal pathway from *D. ventilans* (4D) to the ecosystem (2D) is fully visible and adjustable in the interface. The `hyperMix` slider is a causal dial. The *4D Projection* view shows exactly what *D. ventilans* is doing at every frame. The *Flow Field* view shows the velocity field coupling prey and morphogen. There are no hidden variables.
This is the claire principle made literal: Causal, Legible, Auditable, Interpretable, Robust, Explainable. A 4D organism influences a 2D world — and the influence is completely observable.

§6 Flow Field Advection

Inspired by Flow-Lenia (Plantec et al., 2022), Genesis adds a velocity field derived from channel gradients that advects the entire state before each convolution. This adds large-scale fluid dynamics on top of the local reaction–diffusion.

```
// Mode 0: Gradient flow
// Prey flows along morphogen gradient; prey curl generates vorticity
vel = grad(A2) * 3.0 + curl(grad(A0)) * 1.5

// Mode 1: Curl flow (purely rotational)
vel = curl(grad(A0)) * 4.0

// Mode 2: Spiral flow
angle = atan(centered.y, centered.x) + u_time * 0.3
vel   = radial(centered) * r * 2.0 + grad(A2) * 2.0

// Pack into [0,1] (0.5 = zero velocity), output to flowTex
outColor = vec4(vel * 0.15 + 0.5, 0.5, 1.0)

// Applied in SIM_FRAG as backward advection:
advUV = fract(v_uv - vel * texel * u_flowStr)
prev  = texture(u_state, advUV)
```

Listing 5: flow_frag — three advection modes. The spiral mode produces galaxy-like large-scale structure.

The flow field makes all channels *fluid*: prey concentrations drift along morphogen gradients, predator populations are carried in the wake of prey motion, and the morphogen field itself swirls. In *Spiral* mode, the entire simulation develops galaxy-like large-scale structure — rotating arms of prey with predators chasing along the trailing edges.

§7 Behavioral Observations

Preset	Key observation
Duel	Prey solitons orbit then merge under predator pressure. Predator collapses when prey exhausted; reseeding required. Morphogen trails persist 40–60 frames post-death.
Swarm	Arms race: prey cluster in morphogen-depleted voids to evade predator. Predators converge on highest-density prey patches. Stable coexistence occasionally at $c_{01} \sim 0.3$, $c_{10} \sim 0.4$.
Coexist	Separated factions develop distinct morphogen territories. At contact boundary: dramatic species interaction — sometimes competitive exclusion, occasionally stable interface.
Invasion	Predator wavefront propagates ~ 2–3 cells / sim-second. Burned region behind front resists recolonization — morphogen depleted. Prey occasionally outflank via toroidal wrap.
dv Seed	Prey nucleates in annular band at outer *D. ventilans* ring radius ($\sim 85\%$ of grid radius). Band rotates with zw speed. xw/yw rotation breaks symmetry, creates asymmetric prey patches. *D. ventilans* is *invisible* in ecosystem view.
4D View	*D. ventilans* ring maximally visible at W-slice $= 0$. Vanishes near $W = \pm 0.8$. Three β-weighted rings ($R/3$, $R/2$, $5R/6$) clearly distinguishable. Outer ring $\sim 12\times$ brighter than inner — dominant as expected.
Flow: Curl	Prey generates vorticity; spiral structures self-organize. Predators orbit prey cores. Stable rotating assemblies occasionally form and persist for hundreds of frames.
Flow: Spiral	Galaxy-like large-scale structure. Rotating arms of prey, predators trailing along leading edges. *D. ventilans* ring seeds new prey in the arm that sweeps over its position.

Table 6: Behavioral observations by preset and mode. All observations at default parameters; coupling strengths $c_{01} = 0.35$, $c_{10} = 0.40$.

§8 Open Questions

8.1 True 4D simulation

A full 4D Lenia grid simulation — impractical at $N = 256$ but possible at $N = 32$–64 — would let *D. ventilans* dynamically respond to its own projected influence on the 2D world. The analytical approximation fixes *D. ventilans*'s shape; a true simulation might reveal that the 4D–2D coupling warps *D. ventilans*'s own 4D body over time: *an organism shaped by its own shadow.*

8.2 Phase locking

If the *D. ventilans* breath period matches the prey–predator Lotka–Volterra period, resonance effects might produce dramatically amplified prey bursts at the moment of maximum *D. ventilans* visibility. Can `hyperMix` tuning phase-lock these two oscillation systems?

8.3 Other 4D species

Chan's `animals4D.json` contains multiple named 4D organisms. Do any exhibit translational dynamics in 4D that would produce a moving 2D nucleation point — a traveling seed source rather than a stationary ring? Could such an organism *walk* across the 2D ecosystem, leaving trails of spontaneous prey?

8.4 2D relatives

Does $\boldsymbol{\beta} = (\frac{1}{12}, \frac{1}{6}, 1)$ produce stable so species in 2D Lenia at modified μ–σ values? If so, is there a continuous parameter path from those 2D species to *D. ventilans* — a topological deformation across dimensional boundaries?

8.5 Morphogenetic memory

At high `hyperMix` values, does *D. ventilans*'s rotation generate a *persistent* morphogen ring (via prey secretion) that outlasts the *D. ventilans* cross-section's visibility? If so, *D. ventilans* leaves a physical record in a field that modifies the physics of every organism that passes through it — a kind of 4D memory inscribed in 2D matter.

8.6 Synchronization across multiple DV instances

If two analytical *D. ventilans* generators are seeded with different zw phase offsets, do the prey populations they nucleate exhibit interference patterns — *constructive* (prey burst) when both rings overlap, *destructive* (prey famine) when they cancel? This would be 4D organism interference visible in 2D ecology.

§9 Teármann Research Context

9.1 The Layer 4 thesis

The Teármann theoretical framework proposes *Layer 4* reasoning: the ability to reason *across* causal graph structures rather than *within* a fixed one — counterfactual reasoning that operates at the level of the structural causal model, treating the graph structure itself as a variable. Pearl (2009)'s do-calculus and Correa & Bareinboim (2020)'s ctf-calculus operate within a given graph; Layer 4 reasons about which graph to use.

D. ventilans is a *physical instantiation* of this concept. The organism exists in a causal structure (4D Lenia) that is inaccessible to 2D observers. Its influence on the 2D ecosystem is fully real but cannot be represented within the 2D causal graph — *D. ventilans* is a variable that belongs to a higher-level causal model. Layer 4 reasoning would be capable of explicitly representing the 4D structure and intervening on the 4D–2D coupling.

9.2 Shoal-Broadcast and the morphogen channel

The Shoal-Broadcast architecture proposes that agents communicate not through discrete messages but through perturbations in a shared continuous scalar field — the *shoal field*. The morphogen channel (ch2) in Genesis is exactly this: a continuous medium secreted by prey and predator alike, modulating the physics of survival for every organism that moves through it. *D. ventilans* adds a higher-order broadcast layer: the 4D shadow modulates ch0 (prey) which modulates ch2 (morphogen) which modulates the physics of ch0 and ch1 — a three-level broadcast cascade originating in 4D.

9.3 Rukha and the counterfactual engine

Rukha (a companion project) is a counterfactual narrative engine grounded in Pearl's do-calculus and the Correa–Bareinboim ctf-calculus. The *D. ventilans* ecosystem generates exactly the kind of causally transparent data Rukha is designed to annotate: a sequence of events (prey nucleation, predator convergence, morphogen trail formation) with completely observable causal provenance. Each frame is a data point for a causal event graph where the 4D seeding variable (`ch3`→`ch0`) is fully observable and quantifiable via the `hyperMix` value.

乙超球 · *Dihypersphaerome ventilans*

so · *ventilans* · R=10 · β=$(\frac{1}{12}, \frac{1}{6}, 1)$ · μ=0.18 · σ=0.033
4D hyperspherical oscillator · Chan 2020 · code 3Hy2v · Teármann 2026

Mathematical Appendix

A Kernel normalization

The raw kernel weights must be normalized so that K integrates to unity over the full neighborhood (i.e. a uniform state $A \equiv 1$ yields $U \equiv 1$). For a discrete 2D grid at resolution $\Delta x = 1/R$,

```
sum = 0
for dy in [-R, R]:
  for dx in [-R, R]:
    r = sqrt(dx^2 + dy^2) / R
    if 0 < r < 1:
      ri = floor(r * 3)
      t  = r * 3 - ri
      sum += beta[ri] * kcore(t)

K_normalized(r) = K_raw(r) / sum

// For DV params: sum is dominated by the outer ring (beta_3 = 1).
// Inner rings contribute < 14% of total weight combined.
```

Listing 6: Kernel normalization.

B Growth-function fixed points

The growth function $G(u) = 2\exp\bigl(-(u-\mu)^2/2\sigma^2\bigr) - 1$ has three fixed points in $[0,1]$: $G = 0$ at $u = \mu \pm \sigma\sqrt{2\ln 2}$. For *D. ventilans*: $u_{\text{eq}} = 0.18 \pm 0.033 \cdot 1.1774 = \{0.147, 0.213\}$. A cell is in equilibrium (neither growing nor dissolving) when its neighborhood potential lies exactly in this pair. The organism's stable breathing cycle is a limit cycle that oscillates around the equilibrium manifold $\{U(x) = 0.18$ for all x in organism body$\}$.

C 4D volume and surface scaling

In n dimensions, for a shell at radius r with thickness $\mathrm{d}r$:

$$\mathrm{d}V_n = C_n\, r^{n-1}\, \mathrm{d}r, \qquad C_n = \frac{2\pi^{n/2}}{\Gamma(n/2)}. \tag{4}$$

For $n = 4$: $C_4 = 2\pi^2$. The surface area of *D. ventilans*'s outer S^3 shell is $A_3 = 2\pi^2 r^3$ — scaling as r^3 — while the 4D ball volume scales as r^4. At $r = 5R/6$ for *D. ventilans* with $R = 10$, the outer shell radius is ~ 8.33 grid cells and its "4D surface area" (in grid-cell units) is ~ 3625 cells, versus the total 4D ball volume of ~ 3801 cells. The organism is almost entirely surface — the interior volume is negligible relative to the 4D surface it presents to the kernel.

References

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